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GLACIAL LAKE HITCHCOCK IN THE VALLEYS OF THE WHITE AND OTTAUQUECHEE RIVERS, EAST-CENTRAL VERMONT

by

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INTRODUCTION

There are two main purposes of this field trip. One is to review Late Wisconsinan glacial stratigraphy at two exposures in West Lebanon, New Hampshire, where outwash older than the last glacial advance can be observed. The other is to address the question of the relative ages of glacial Lake Hitchcock, glacial Lake Winooski, and the Champlain Sea. Field trip stops will be made on the following U.S.G.S. 7.5-minute quadrangles: Hanover, Vt-NH; Quechee, Vt; Sharon, Vt; Randolph, Vt; and Brookfield, Vt. In addition, the field trip passes through the South Royalton, Vt, and Randolph Center, Vt, quadrangles. Erosion of complex metamorphic rocks by streams and continental ice sheets has produced a rugged, hilly topography with 800 to 1,000 feet of local relief. Drainage is controlled by the Connecticut River which flows south-southwest through the area. Three major tributaries of the Connecticut River in this area are the White, Ottauquechee and Mascoma Rivers.

The area probably has been covered by ice sheets several times but specific evidence of multiple glaciation in east-central Vermont and west-central New Hampshire has not been demonstrated. Multiple-till exposures representing two separate glaciations are known in northern, east-central, and southern New Hampshire (Koteff and Pessl, 1985), as well as in southern Quebec and southern New England. The margin of the last ice sheet retreated northward from Long Island at least by 19,000 years ago (Sirkin, 1982), and the Quebec Appalachians were deglaciated by 12,500 years ago (McDonald and Shilts, 1971). Therefore, the ice margin retreated through the field trip area between 19,000 and 12,500 years ago. Using linear interpolation and assuming a steady rate of ice margin retreat, we can guess that the ice margin retreated through the area between 14,000 and 15,000 years ago. However, the ice probably had an increasing rate of retreat through this area.

Stewart (1961), and Stewart and MacClintock (1964, 1969, and 1970) recognized three separate drift (till) sheets in Vermont and westernmost New Hampshire. They named (1) a northwest-derived Bennington drift, (2) a northeast-derived Shelburne drift, and (3) a northwest-derived Burlington drift. Most of

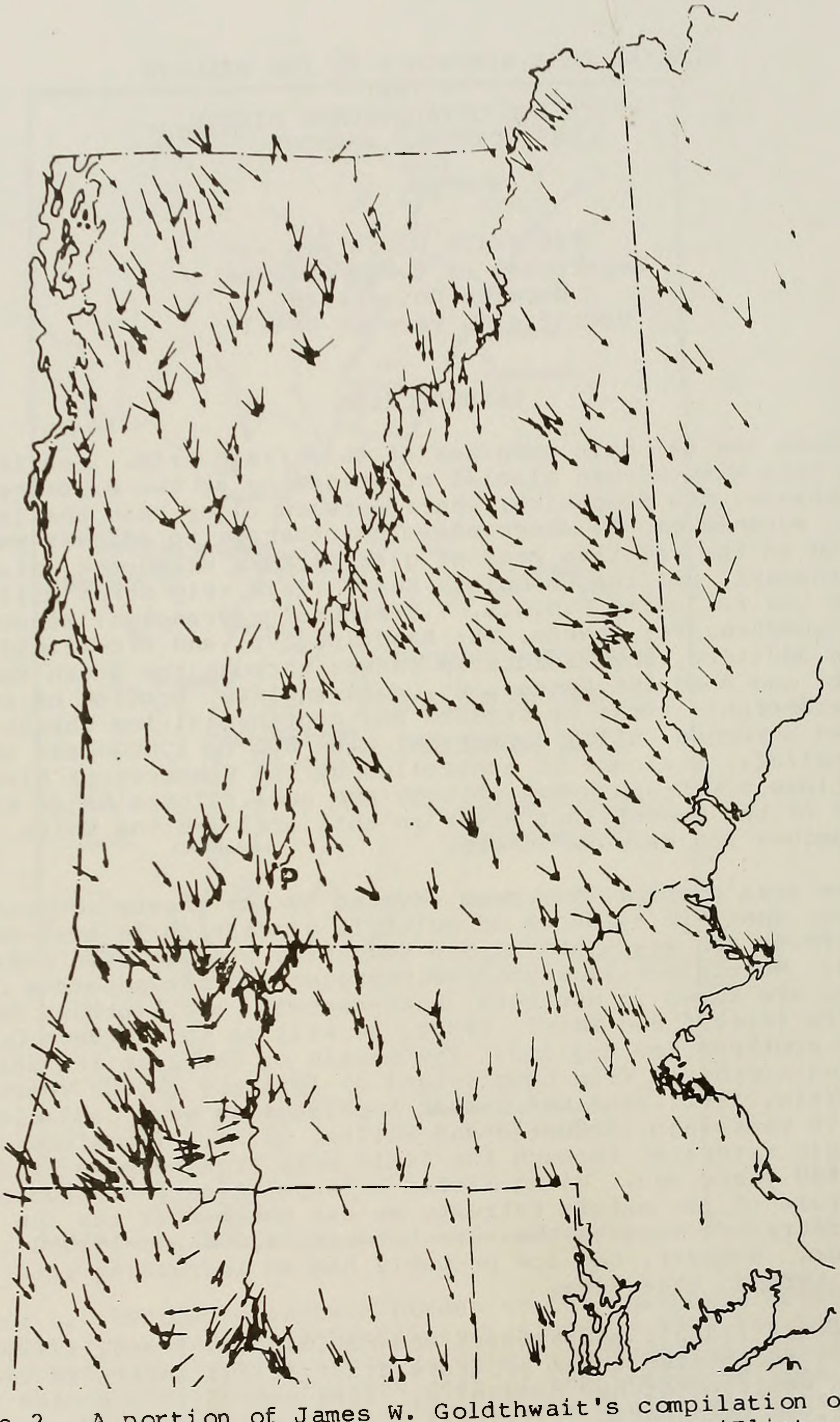

Figure 2. A portion of James W. Goldthwait's compilation of glacial striations in New England; P, Putney, Vt., (Flint, 1957, p. 60).

the area of this field trip lies in the area of the so-called Shelburne drift (Fig. 1). The Shelburne drift was found not to exist at its type locality (Wagner, Morse and Howe, 1972) and 8 of 9 indicator fans mapped in the area of the Shelburne drift are oriented to the south-southeast. According to Stewart and MacClintock, they should be oriented to the southwest of their source areas. I believe that the model of three drift sheets in Vermont and New Hampshire is untenable and that the surface till of New England resulted from the advance and retreat of one ice sheet, the Late Wisconsinan (Laurentide) ice sheet.

During retreat of the ice sheet in this area, the ice margin was accompanied by a northward-expanding glacial Lake Hitchcock (Lougee, 1939, 1957). Lake Hitchcock developed a stable outlet over a bedrock threshold at New Britain, Connecticut, and drainage down the present-day course of the Connecticut River was blocked by a large ice-contact delta at Rocky Hill, Connecticut (Stone and others, 1982). Recent work by Koteff and Larsen (1985 and in prep) indicates that the former shoreline of Lake Hitchcock now rises toward about N21.5°W with a gradient of 0.90 m/km (4.74 ft/mi). The lake formed during ice retreat when the land was still depressed by the weight of the ice, and it extended 320 km from its spillway to West Burke, Vermont, before uplift due to the removal of the weight of the ice sheet commenced. Deltaic and lake-bottom deposits associated with Lake Hitchcock will be observed at several stops on this field trip.

At its maximum extent, an arm of Lake Hitchcock extended up the valley of the Second Branch of the White River and into Williamstown Gulf in central Vermont. Gravel bars located in the valley bottom near East Brookfield appear to have been formed by the outlet stream from glacial Lake Winooski after Lake Hitchcock drained (Larsen, 1984). This would seem to indicate that the dam for Lake Hitchcock had been breached while glacial ice still blocked the northwest-draining Winooski River. However the level of Lake Hitchcock lowered, whether it was by a rapid breaching of its dam or by slow rebound of the crust, or by both, the Connecticut River eventually cut down through the sediments of Lake Hitchcock leaving former flood plains elevated as stream terraces above the level of the modern flood plain. Stream-terrace deposits will be observed at Stops 1 and 2.

No mention has been made of glacial Lake Upham in the above account. The reason for that is twofold. First, that portion of the map of Lake Upham shown by Lougee (1957) to be north of the so-called "Algonkian hinge line" essentially is the same as the shoreline shown by Larsen (1984) and Koteff and Larsen (1985 and in prep) to be the northern part of Lake Hitchcock. Secondly, although many data points (delta elevations) collected by Koteff and Larsen (in prep) fall below the level of Lake Hitchcock, at this time there is no clearly defined single shoreline that one might call "Lake Upham". For these two reasons, I suggest that the term "Lake Upham" be dropped.

Figure 3. Indicator fans in Vermont, New Hampshire, and southern Quebec: 1. Barre; 2. Braintree; 3. Brocklebank; 4. Knox Mt.; 5. Lebanon; 6. Glover; 7. Ascutney; 8. Cuttingsville; 9. Mt. Hereford; solid black, igneous source rocks; black lines down-glacier from plutons are 10% isopleths showing percent of source rocks in till samples. (Sources: 1, Larsen, 1972; 2-8, Great Pebble Campaigns at Norwich University, 1974-78 and 1980-81; 9, McDonald, 1967)

ADVANCE OF THE ICE

During advance of the last ice sheet in this part of the Connecticut Valley, braided meltwater streams issuing from the ice dropped tons of sediment in front of the ice as outwash or valley train deposits. As time went on, the ice sheet overrode these advance outwash deposits and in most areas removed them and recycled them into till or into younger advance outwash further downstream. However, there are three places in east-central Vermont and western New Hampshire where advance outwash deposits can be observed. They are (1) along the Jail Branch southeast of Barre (Larsen, 1972, Stop 1), (2) on the south side of the White River east of Bethel, and (3) in two pits visited on this field trip in West Lebanon (Stops 1 and 2). Advance outwash probably occurs at other sites but exposures are not common.

DIRECTION OF ICE MOVEMENT

The direction of movement of the former ice sheet can be ascertained by a study of striations, roche moutonnée forms, crag-and-tail features, indicator fans, and the orientation of elongated stones in till (till-fabric analysis). Figure 2 shows a portion of a map of glacial striations compiled by James W. Goldthwait (Flint, 1957). Note the fact that along the Connecticut River of east-central Vermont and western New Hampshire striations trend between south-southwest and southeast. Away from the river both on the east and the west the striations are oriented between south-southeast and southeast. I attribute the pattern to one glaciation and to the facts that striations are made at different times during a single glaciation and that the direction of movement of bottom ice may be quite different than the regional gradient on the surface of the ice due to rugged topography.

Support for the idea that ice movement in east-central Vermont was to the south-southeast as shown in Figure 2 came from a series of "Great Pebble Campaigns" at Norwich University. Students in physical geology labs each collected 100 pebbles at selected sites around and south of granitic plutons and other unique source areas. When the percent of indicator clasts at each site was plotted it was found that the highest concentrations were between due south and southeast of each source area studied (Fig. 3).

When we compare the south-southeast orientation of the indicator fan derived from the Lebanon dome (5, Fig. 3) with the southwest orientation of the till-fabric arrows shown in Figure 1 there is an obvious discrepancy. Note on Figure 1 the symbol at Lebanon that shows southwest-oriented surface till over southeast-oriented subsurface till. The location of that Stewart and MacClintock study is taken to be the West Lebanon Sand and Gravel pit (Stop 2) where, today, apparently only one till can be observed. To approach a solution to the problem, till-

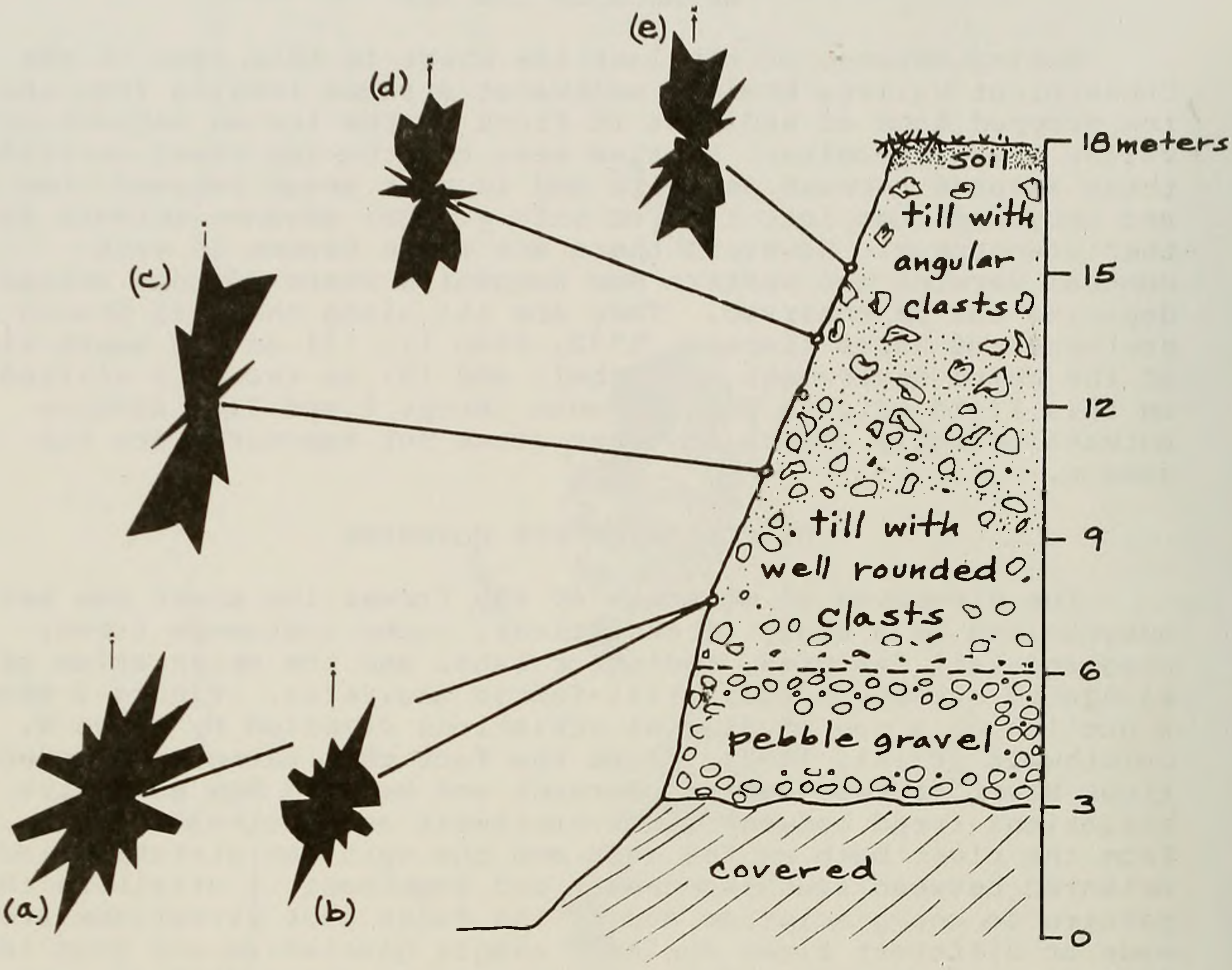

Figure 4. Stratigraphic section at Stop 4, West Lebanon Sand and Gravel pit, showing location of till-fabric studies made in July, 1973, by the following: (a) Steve Tenney, (b) John Cleary, (c) Julian Green, (d) Jim Reynolds, and (e) Tom Lyman. Note the upward change in shape and orientation of the till-fabric diagrams. The more rounded diagrams reflecting more spread of data are at the bottom and the narrower diagrams indicating less spread of data are at the top. The change in orientation from north-northeast/south-southwest at the bottom to north/south at the top reflects a change in the direction of ice movement during deposition of the till.

fabric studies were made during the summer of 1973 by students in a geomorphology class at Dartmouth College (Fig. 4). The till-fabric diagrams in Figure 4 show a change in orientation from north-northeast/south-southwest at the bottom to north/south at the top which reflects a change in the direction of ice movement during deposition of the till. The question remains: when were different parts of the till section deposited? The north/south orientation of the upper two fabric diagrams shown in Figure 4 is more consistent with the south-southeast trend of the Lebanon indicator fan than the southwest trend of "surface till" shown by Stewart and MacClintock.

DEGLACIATION

As mentioned above, based on interpolation, the ice margin retreated through the West Lebanon area between 14,000 and 15,000 years ago. Evidence for that statement comes from the fact that Mirror Lake, NH (altitude 212 meters) was deglaciated by about 14,000 years ago (Davis, Spear, and Shane, 1980). Because Mirror Lake is located 61 kilometers (38 miles) northeast of West Lebanon, it seems reasonable to assume that the West Lebanon area was deglaciated at least by that time.

In Massachusetts, deglaciation of the Connecticut Valley was by an active lobe of ice that readvanced several times (Larsen and Hartshorn, 1982). The active lobe is also shown by a radial pattern of striations stretching across the valley and the distribution of erratics of Jurassic-Triassic rocks transported both east and west of their source area in the Connecticut Valley. Inspection of the Goldthwait compilation (Fig. 2) reveals southwest and west-southwest striations located west of the Connecticut River in both Massachusetts and Connecticut.

A basic question then is how far north was the Connecticut Valley ice margin an active, spreading lobe. I believe the answer lies on the Goldthwait map near Putney, Vt (P, Fig. 2), at the site of a striation that trends about S30°W. On the west side of the Connecticut Valley north of Putney there are no striations that indicate a radial pattern of movement by an active ice lobe. I interpret the lack of a radial pattern of striations to indicate that deglaciation of the Connecticut Valley north of Putney was by a stagnant tongue of ice. In my view the width of the stagnant zone was many kilometers wide and, upglacier from the stagnant ice, the active ice was sluggish at best, showing no sign of lobate flow in late-glacial time.

An important glacial feature that formed in late-glacial time in this area, and one that typically forms in stagnant ice, is the Connecticut Valley esker. It probably was built in segments over a north-south distance of at least 40 kilometers from Windsor, Vt, on the south, to Lyme, NH, on the north. We will not visit the Connecticut Valley esker on this field trip, but excellent exposures in the esker are available for study in

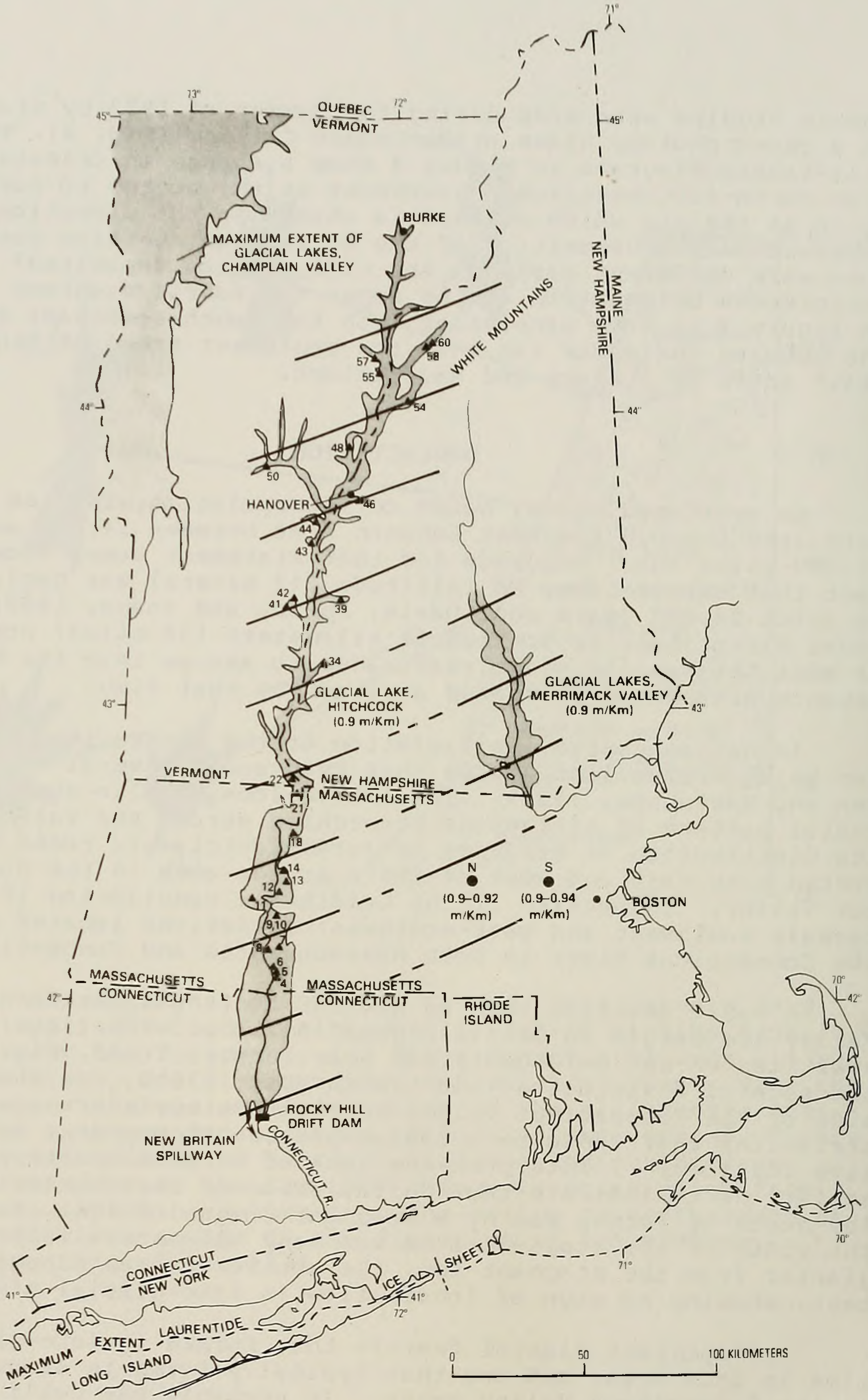

Figure 5. Generalized outline of glacial Lake Hitchcock and selected other glacial lake areas in western New England. (N) glacial Lake Nashua; (S) glacial Lake Sudbury; solid triangles denote location of altitude obtained from unmodified, ice-marginal, or meltwater-derived delta; uplift isobase interval is 25 meters. (Figure from Koteff and Larsen, in prep.)

Hartland, Vt, where the top of the esker rises 40 meters above what was once the floor of Lake Hitchcock. Sediments in the Pike pit, 1.2 kilometers east of Hartland village, display a wide range of grain sizes from interbedded pebbly sand and pebble-cobble gravel in south-dipping crossbeds to fine and very fine sand with ripple crossbedding dipping to both north and south. Large angular blocks, over 1 meter on edge, of bedded fine sand, silt, and clay appear to have dropped into the esker sequence from overlying ice. At the very least, the presence of the Connecticut Valley esker tells us that there was a large subglacial, meltwater stream flowing south into Lake Hitchcock just prior to retreat of the ice margin through this area. Although we do not stop in the Connecticut Valley esker on this trip, sediments of the Sharon esker in the White River valley will be observed at Stop 5.

GLACIAL LAKE HITCHCOCK

As the ice margin retreated through the West Lebanon area it was accompanied by a northward expanding Lake Hitchcock. For an up-to-date treatment of the origin and early history of Lake Hitchcock see Stone and others (1982) and Koteff and others (1987). By the time the ice margin was in the vicinity of the Holyoke Range in Massachusetts, the level of Lake Hitchcock had become stable because downcutting at the New Britain spillway had reached bedrock and ceased. Koteff and Larsen (in prep.) have established the location and orientation of the stable shoreline of Lake Hitchcock by determining the elevation of the topset/foreset contact in many deltas (Fig. 5). The highest 28 deltas are ice-marginal features, consecutively built northward, and define the former shoreline as a plane with a gradient of 0.90 m/km (4.74 ft/mi) toward N21.5°W (Fig. 6). Because the former shoreline appears to be planar, as opposed to being curved, we believe that postglacial rebound did not commence in New England until the ice margin had retreated north of West Burke (Koteff and Larsen, in prep.). If rebound had caused the spillway to rise while ice still occupied the northern part of the Lake Hitchcock basin the youngest deltas would have formed in a rising lake. That would have produced a concave-up projected profile instead of the linear projected profile that we see in Figure 6.

The sediments of Lake Hitchcock that will be seen on this field trip consist mainly of deltaic and proximal lake-bottom deposits. The latter consist of varves with winter clay layers less than 2 centimeters thick and summer layers of laminated very fine sand and silt that typically are 30, 40, 50, or more centimeters thick. These proximal varves occur directly above esker deposits and are often collapsed. I attribute the thickness of the summer layers to the rapid rate of deglaciation of stagnant ice. Proximal varves are well exposed at Stops 1 and 5.

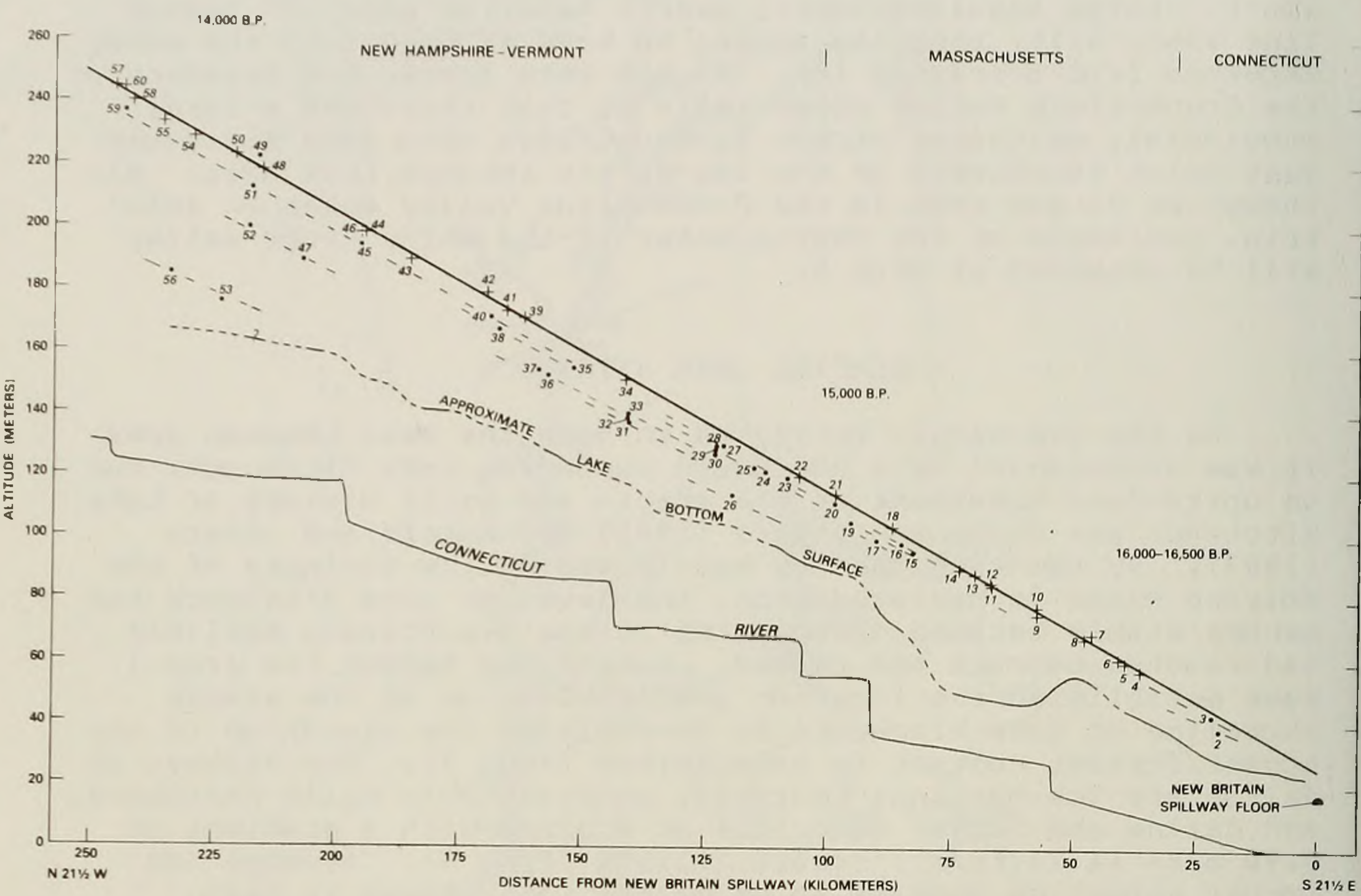

Figure 6. Ordinary least squares regression profile based on altitudes of topset/foreset contacts of 28 unmodified, ice-marginal, or meltwater-derived deltas (+) in glacial Lake Hitchcock. (.) other altitudinal data. Dashed profiles are diagrammatic only. Lake-bottom profile estimated from previous publications and topographic maps. (Figure from Koteff and Larsen, in prep.)

QUECHEE GORGE

When the retreating ice margin was located just north of the present site of Quechee Gorge, an ice-contact delta was formed by meltwater streams flowing into an arm of Lake Hitchcock that extended into the valley of the Ottauquechee River. The original delta extended completely across the valley and was slightly higher than the sandy plain crossed today by U.S. Route 4 just east of Quechee Gorge. Later, after either Lake Hitchcock had drained or postglacial uplift had begun, meteoric water from upstream crossed over the delta plain and lowered the surface by as much as 3 meters. This is shown by fluvial beds overlying lake-bottom sediments at Stop 3.

In time, Lake Hitchcock drained when the Rocky Hill dam was breached. The stream that we know today as the Ottauquechee River was flowing south on the west side of the Quechee delta. As Lake Hitchcock lowered, the Ottauquechee River was easily able to erode down through sand, gravel, and till until it struck ledge. Downcutting slowed abruptly when the ledge was encountered but nonetheless it continued to the present day to produce one of the top geologic and scenic features of Vermont.

The preglacial valley of the Ottauquechee River is located under the east side of the Quechee delta. A well, located near U.S. Route 4, 1.1 kilometers east of Quechee Gorge, has over 35 meters of unconsolidated sediment and a second well, 366 meters east of Quechee Gorge and 30 meters south of U.S. Route 4, has 42 meters of fine sand overlying 5 meters of till (James W. Ashley, 1987, pers. commun.). The Ottauquechee River could not slip laterally down along the bedrock ridge it encountered during downcutting and back into its preglacial valley because of a bedrock high located 198 meters N75 E of the east end of the bridge over Quechee Gorge. The bedrock is exposed above the level of U.S. Route 4 and has faint striations trending due south.

WILLIAMSTOWN GULF

Lake Hitchcock eventually extended up the valleys of the White River and its tributaries. Its maximum northward extent in the White River basin was up the valley of the Second Branch and 1.6 kilometers into Williamstown Gulf, a narrow V-shaped valley about 2.5 kilometers long. Located just south of the lowest drainage divide (279 meters/915 feet) between the Winooski River basin and the White River basin, Williamstown Gulf must have been occupied by an outlet stream from a glacial lake whenever the Winooski River was blocked on the northwest by glacial ice. If we accept two major glacial advances and retreats between the St. Lawrence Lowland and southern New England during the Wisconsinan (Koteff and Pessl, 1985), then by necessity Williamstown Gulf was eroded by a major outlet stream on four occasions during the Wisconsinan, that is, during each advance and retreat of the ice sheet. Williamstown Gulf is,

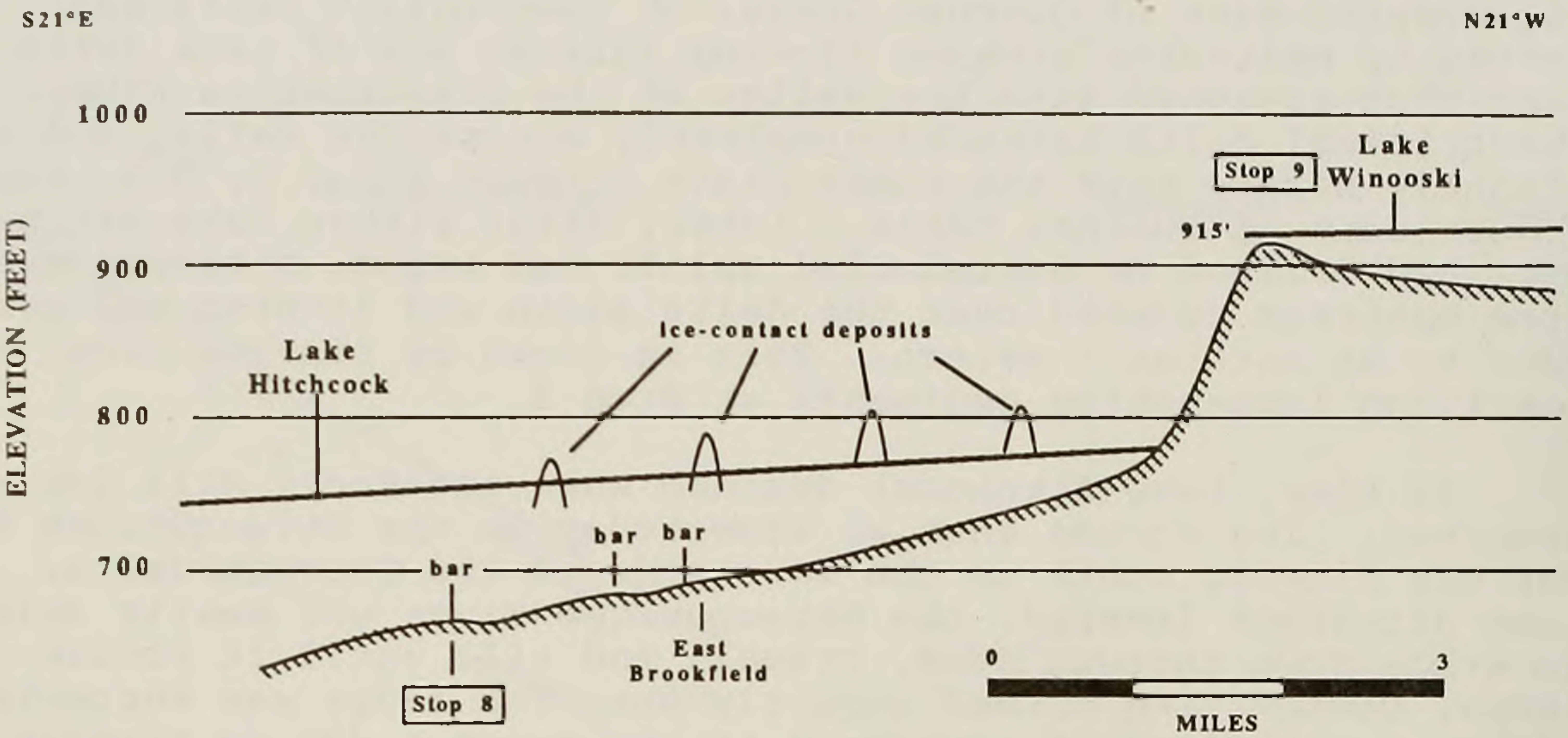

Figure 7. Projected profile oriented N21°W-S21°E of Lake Hitchcock shoreline in relation to gravel bars on the valley floor of the Second Branch of the White River.

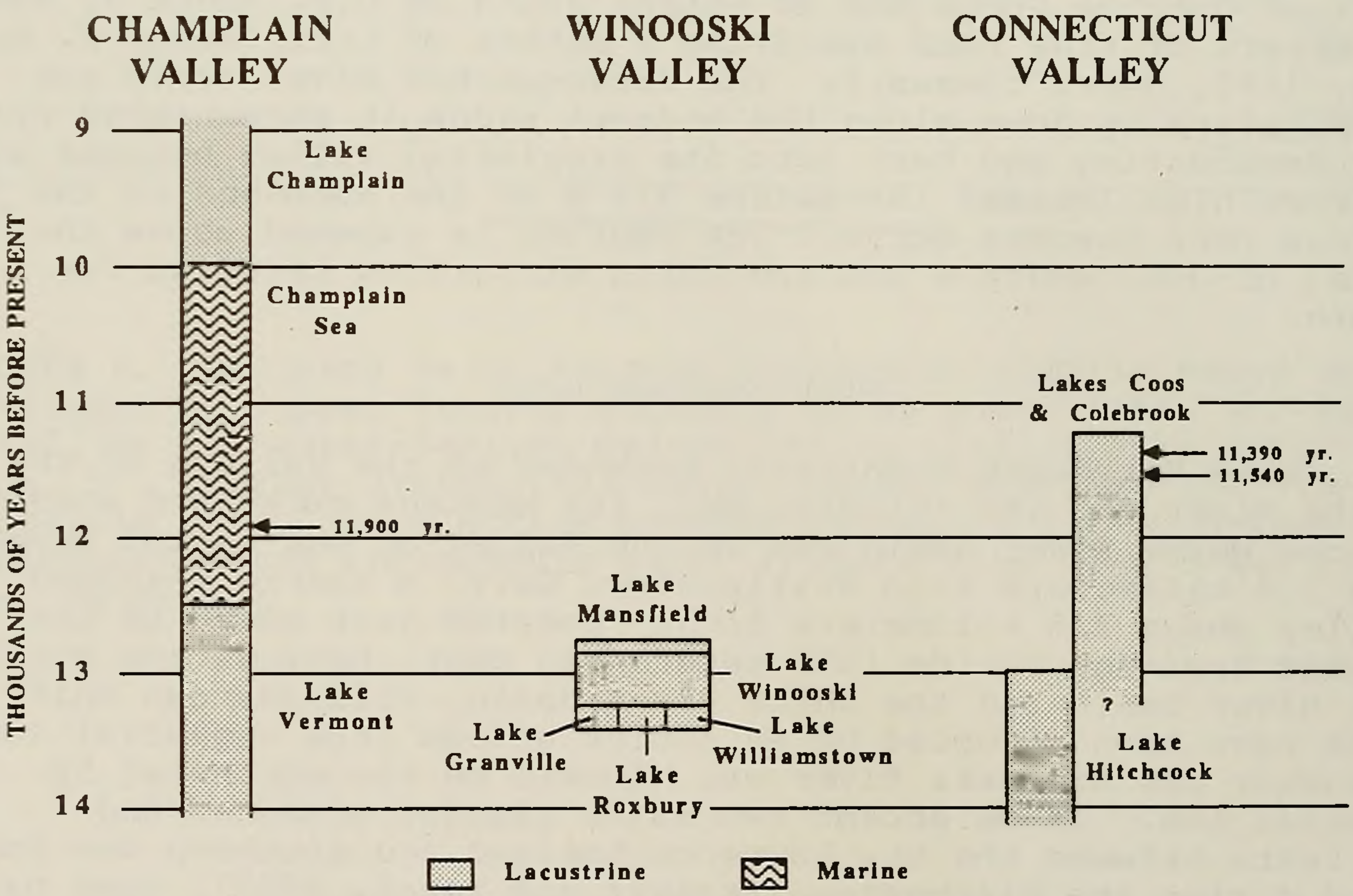

Figure 8. Chronology of glacial lakes in the Champlain, Winooski, and Connecticut valleys in relation to C-14 dated Champlain Sea.

therefore, a relic landform. It bears a special fluvial imprint in an otherwise glacial landscape.

RELATIVE AGES OF LAKE HITCHCOCK, LAKE WINOOSKI, AND THE CHAMPLAIN SEA

Glacial Lake Winooski developed in the northwest-draining Winooski valley after the margin of the ice sheet retreated north of the 279-meter threshold located 4.0 kilometers south of Williamstown, Vt. Meltwater from the ice sheet passed through Lake Winooski, over the threshold and into Williamstown Gulf where, at an elevation of about 237 meters (777 feet), it joined Lake Hitchcock (Fig. 7). Four small ice-contact deposits (deltas?) are located on the valley side between the south end of Williamstown Gulf and a point 1.9 kilometers south of East Brookfield. These four deposits fall on or near the projected level of Lake Hitchcock, and are believed to have been deposited directly into Lake Hitchcock (Fig.7).

Longitudinal gravel bars up to 300 meters in length occur along 7 kilometers of valley floor in the vicinity of East Brookfield. The bars, difficult to see on the ground, are easily viewed on aerial photographs. The bars are composed of pebble gravel with some cobbles in horizontal layers or in sheets that are parallel to the bar surfaces that are convex-up in both longitudinal and transverse profile. The bedding is indistinct except that some gravel layers have a sand matrix. Sand layers and sedimentary features formed in the lower-flow regime are absent. The gravel layers were all deposited in the upper-flow regime by a large stream under flood conditions. I interpret that stream to have been the outlet stream from Lake Winooski after Lake Hitchcock had drained, because the minimum projected level of Lake Hitchcock is 25 meters above the bar surface at Stop 8, 3.0 kilometers south of East Brookfield (Fig. 7).

If that is true, then it is possible to establish a minimum age for the draining of Lake Hitchcock by inspecting the chronology of glacial lakes in the Champlain, Winooski, and Connecticut Valleys in relation to the Carbon-14-dated Champlain Sea (Fig. 8). Lake Winooski continued to exist while the ice margin retreated down the Winooski valley to the northwest toward the Champlain Valley. When the ice margin reached the vicinity of Jonesville, Vt, on the west side of the Green Mountains, Lake Winooski drained and water no longer flowed south over the 279-meter threshold in central Vermont.

A sequence of four separate ice-marginal lakes formed in the valley of the Huntington River as Champlain Valley ice melted from the lower Winooski valley (Wagner, 1972). Eventually, an arm of glacial Lake Vermont occupied the lower Winooski valley as far east as Waterbury. With retreat of the ice margin in the Champlain Valley, glacial Lake Vermont extended northward into Quebec. Ice in the St. Lawrence Valley disintegrated and about 12,500 years ago (Gadd and others, 1972), marine waters of the Champlain Sea replaced Lake Vermont (Fig. 8). The Champlain Sea existed from about 12,500 to 10,000 years ago at which time crustal rebound raised the threshold of the Champlain basin to sea level, which caused the freshening of Lake Champlain.

The conclusion I reach is that the draining of Lake Hitchcock occurred while Lake Winooski existed and several hundred years before any marine sediments were deposited in the Champlain Valley. If we accept the date of 12,500 BP as the time of marine incursion, then the draining of Lake Hitchcock could easily have occurred at or before 13,000 BP.

ACKNOWLEDGMENTS

Literally hundreds of students at Norwich University participated in one or more "Great Pebble Campaigns". Without their help, the map of indicator fans in Vermont (Fig.3) would not have been possible. Five Dartmouth College students produced the till-fabric diagrams shown in Figure 4. James H. Reynolds, III, supplied the computer drawings in Figures 7 and 8. Carl Koteff reviewed the paper and made suggestions for its improvement. To all these people I extend my sincere thanks.

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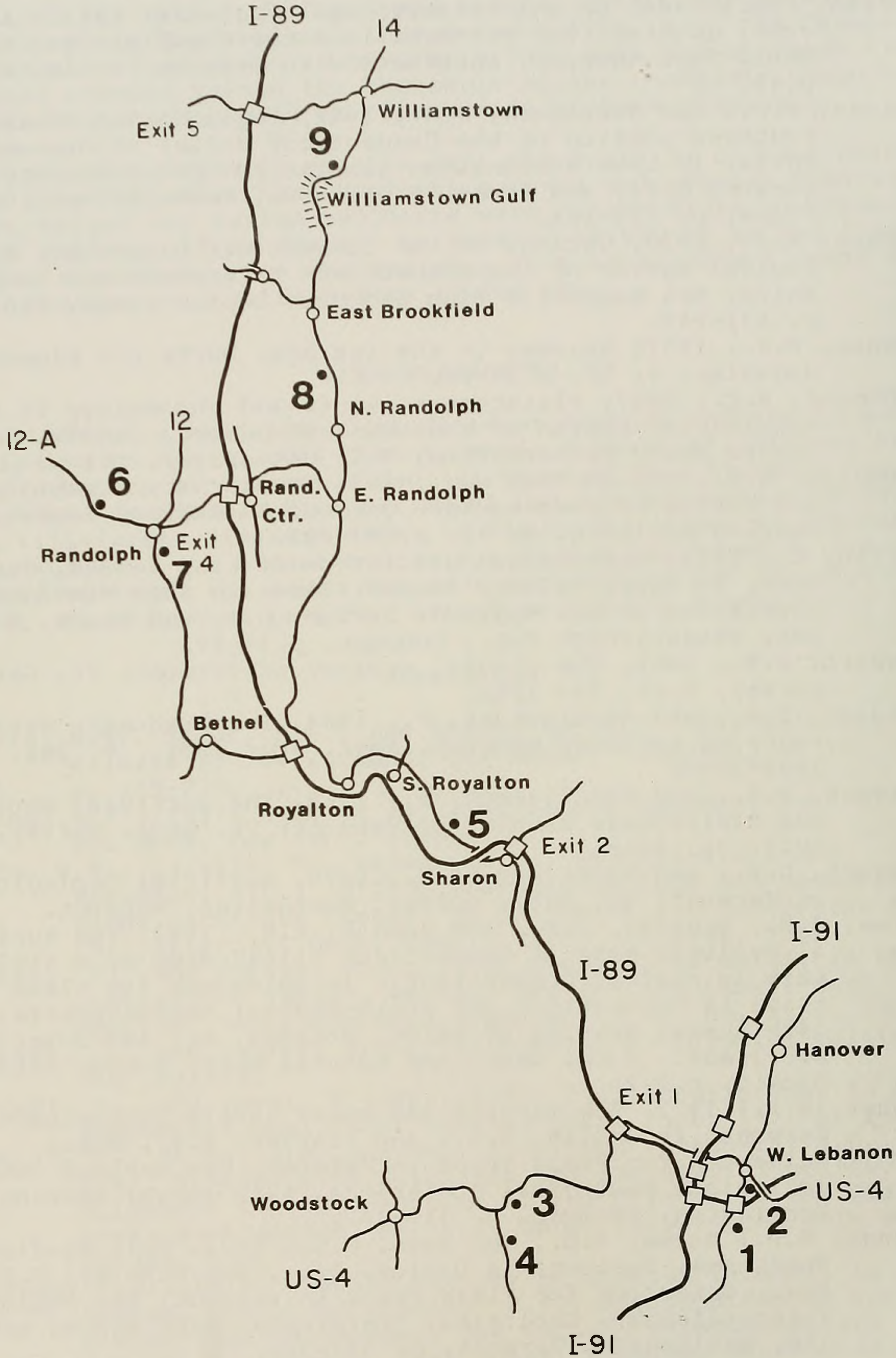

Figure 9. Location of field trip stops.

Road Log

START AT PARKING LOT AT McDONALD'S RESTAURANT, N.H. ROUTE 12A, 0.25 MILE SOUTH OF INTERCHANGE 20, ROUTE I-89, WEST LEBANON, NEW HAMPSHIRE

Mileage
0.0 Begin mileage and turn right (east) on Interchange Drive

0.1 Turn left on Plaza Heights

0.3 Turn right between two large buildings, park in pit area

STOP 1. MOULTON CONSTRUCTION CO. PIT.

EAST FACE: The owners request that visitors stay away from the steep east face which has a total height of about 23 meters. From the bottom up the section consists of 8.4 meters of pebbly coarse sand in trough crossbeds that consistently dip to the south. Next is a massive layer, 2.7 meters thick, composed of pebble gravel with cobbles. Above the massive gravel layer is a 4.6-meter unit similar to that at the base with trough crossbeds that dip to the south. Capping the section is 4.6 meters of gray, compact till that is overlain on the south by 1 meter of brown fine to very fine sand. The sequence is interpreted to be advance outwash at the base with the overlying till representing the advance and retreat of the Late Wisconsinan ice sheet. The sequence does not represent a readvance of the last ice sheet because during retreat the margin of the last ice sheet was accompanied by a northward-expanding glacial Lake Hitchcock. A readvance in a glacial lake should result in a section with till overlying lacustrine sediments, not fluvial sediments as seen here.

SOUTHWEST FACE: At the base 1.0 meter of loose coarse sand and pebble gravel is overlain by 3.2 meters of compact diamict made up of pebble gravel with cobbles and boulders. The clasts in the diamict are rounded to angular and are up to 1.0 meter in diameter. Above the diamict is 5.0 meters of laminated very fine sand, silt, and clay in proximal varves up to 60 centimeters thick. In places, up to one half meter of loose pebble gravel lies between the diamict and the varves. Stream terrace gravel overlies the varved sediments at the south end of the pit. The 1.0 meter of loose gravel at the base is interpreted to be advance outwash. The diamict is believed to be the Late Wisconsinan till that here was derived from coarse advance outwash and the varves are interpreted to be the bottom sediments of Lake Hitchcock. At the top, thin stream-terrace deposits represent a stage in downcutting through older sediments by the Mascoma River or the Connecticut River.

Retrace route to NH Rt 12A

0.8 Turn right (north) on Rt 12A

1.0 Proceed north under Interstate I-89

2.3 Turn right (east) on U.S. Route 4 and immediately

2.33 Turn right (south) on Elm Street, proceed south

2.7 Gate to Twin State Sand and Gravel

2.9 Near office turn left and descend to active pit

STOP 2. TWIN STATE SAND AND GRAVEL PIT.

SOUTHEAST FACE: Walk southeast to face with 10 meters of till overlying pebble gravel. The section is interpreted to be Late Wisconsinan till overlying advance outwash. The lower portion of the till is rich in well rounded pebbles. Measurements for the till-fabric diagrams shown in Figure 4 were made at this site.

ACTIVE PIT: At the west end the section consists from the bottom up of: (1) 2.5 meters of pebbly sand in south-dipping trough crossbeds, (2) 3 meters of pebble gravel in flat to gently dipping beds, (3) 3.2 meters of pebbly medium sand with trough crossbeds, (4) 0.5 to 3.0 meters of pebble-cobble gravel in well developed channels, (5) up to 1.0 meter of fine sand with a well developed soil profile, and (6) 4.0 meters of artificial fill made up of well bedded fine sand that probably was deposited in a man-made settling pond similar to that now found just to the south. I believe that the lower 8.7 meters is advance outwash formed in a proglacial braided stream. The poorly sorted pebble-cobble gravel in channels and the fine sand constitute stream-terrace deposits that were formed as alluvium by the Mascoma River as it cut laterally to the north into a scarp underlain by till. The channels represent flood events in the Mascoma drainage basin while lateral cutting took place.

Proceed southwest up and out of pit

3.2 Turn right on tar road, proceed north out of pit

3.8 CAUTION. Turn left (west) on US Route 4 and turn left (south) on NH Rt 12A

4.8 Turn west on I-89 North at Interchange 20

5.3 Cross Connecticut River and enter Vermont

5.6 DO NOT EXIT ON I-91, CONTINUE WEST ON I-89

6.6 Projected shoreline of Lake Hitchcock passes through the site of the V.A. Hospital at the right

8.8. Turn right from I-89 at Exit 1

9.1 Turn left (west) on US Route 4

11.9 Surface of Quechee delta

12.3 Red Pines Restaurant on right was the site of an excavation where the topset/bottomset contact was exposed in 1982

12.4 Turn right and drive behind Restaurant-Dana's at the Gorge

STOP 3. QUECHEE ICE-CONTACT DELTA.

The topset/bottomset contact of the delta was measured to be 194.4 meters (638 ft) ASL. Pebbly coarse sand is exposed at the surface and very fine sand and silt are found draping the bedrock knobs. The projected level of Lake Hitchcock at this site is about 197.5 meters (648 ft) ASL. Because there are no deltaic foreset beds exposed below the pebbly coarse sand, it is presumed that they were removed by at least 3.1 meters (10.2 ft) of erosion at this site.

Quechee gorge resulted from the superposition of the Ottauquechee River which was located on the west side of the delta when Lake Hitchcock drained. The preglacial course of the river is at the east end of the delta.

Proceed west on US Route 4 across the Quechee Gorge bridge

13.3 Turn left (south) on Quechee Road at blinking light

13.6 Channel on right (now occupied by man-made pond) leads to saddle between two hills; melt-water that fed the ice-contact delta at Stop 4 passed through this saddle to the southeast

13.9 The bank between the pond on the left and the road marks the ice-margin position when the ice-contact delta was being built

14.1 Turn left (east) into pit road, park next to gate

STOP 4. ROBERT SEERY PIT.

Note the pebble-cobble gravel at the top of the north face of the pit. The section at the south face from the bottom up consists of 2 meters of light brown fine sand covered by 2 meters of pebbly coarse sand and pebble gravel in trough cross-beds. Fine sand with pebbles, about 0.3 of a meter thick, caps the gravel and is interpreted to be eolian in orgin. The contact between the gravel and the underlying fine sand is thought to approximate the topset/foreset contact and was measured to be 197.5 meters (648 ft) ASL.

Retrace route north to US Route 4

14.9 Turn right (east) on US Route 4 at blinking light

15.6 Pass over Quechee gorge

18.9 Turn right, enter Interstate I-89 North at Exit 1

24.0 Sharon Rest Area

28.8 Turn right, leave I-89 North at Exit 2

29.1 Turn left at end of ramp

29.3 Turn right on Route 14 in Sharon, proceed west

30.3 Pass under I-89 bridge over the White River

31.0 Thick varves of Lake Hitchcock exposed on right

31.7 CAUTION, TURN LEFT ACROSS TRAFFIC, PARK IN REST AREA

STOP 5 SHARON ESKER

The face is oriented northwest-southeast and is about 240 meters long and up to 35 meters high. A section was measured 88 meters northwest of the culvert in the v-shaped notch and had 3 units. At bottom unit had 20.6 meters of interbedded pebble-cobble gravel, pebble gravel, and coarse sand. Open-work structure in the gravels and dune crossbedding dipping to the southeast are common. The environment of deposition for the lower unit was a high energy stream in a subglacial tunnel. The second unit is 9.8 meters thick and consists of varves up to 50 centimeters thick that represent bottom deposits of Lake Hitchcock. The third unit, exposed at the top, is 2.2 meters thick and is made up of stream-terrace deposits. Most of the varves dip 30 to 40 degrees to the northeast indicating they were deposited on or adjacent to ice that later melted.

Proceed northwest on Route 14

34.6 Village of South Royalton

35.4 Excellent exposure of graded beds in the Gile Mountain Formation (Devonian) at river level

36.1 Narrow railroad underpass

36.6 Village of Royalton

37.4 Narrow railroad underpass

38.1 Turn left (west) on Route 107

38.7 Turn right, enter I-89 North at Exit 3

47.3 Turn right from I-89 at Exit 4, turn left (west) on Route 66

50.3 Proceed straight at blinking red lights, Route 66 ends, join Route 12

50.4 At junction leave Route 12 and proceed straight on Route 12A west and northwest up the valley of the Third Branch of the White River

53.5 Turn right on dirt road and immediately turn right again on road to pit

STOP 6 PIT IN LOWER BRANCH DELTA

The topset/foreset contact seen at the north end of this pit has only recently been exposed. The topset beds are 1.1 meters thick and are composed of poorly sorted pebble-cobble gravel. The foreset beds are at least 2.4 meters thick and are composed of clean pebble gravel and pebbly coarse sand with open-work structure being common. The foreset beds dip toward N55°E indicating that they were deposited by melt-water streams flowing from a stagnant tongue of ice in the Third Branch valley to the west. The topset/foreset contact has been trimmed indicating that some erosion of the foresets has taken place. The topset beds are poorly sorted in contrast to the foresets and were derived by a stream flowing from north to south down over the delta surface. The elevation of the topset/foreset contact was measured to be 228.3 meters (749.0 feet) ASL.

Retrace route to Randolph

53.8 Turn left on Route 12A

56.8 Turn right (south) on Route 12

57.2 Railroad tracks in center of Randolph, proceed south and rise up onto surface of Randolph ice-contact delta

57.7 Pull U-turn in vicinity of Gifford Memorial Hospital and park on east side of Route 12

STOP 7 RANDOLPH ICE-CONTACT DELTA

The surface elevation is about 228.7 meters (750 feet) ASL at the intersection of Route 12 and Highland Avenue. The surface slopes to the southeast and is underlain by pebbly sand. A similar surface lies 0.8 of a mile to the north. I interpret the landform to be an ice-contact delta that was formed in Lake Hitchcock by meltwater issuing from a stagnant tongue of ice the margin of which was located just west of the village of Randolph.

Proceed north on Route 12

58.5 Bear right on Route 12

58.6 Blinking red lights, turn right onto Route 66

61.3 Proceed east over I-89

62.0 Turn sharp left (north) in Randolph Center

62.6 Turn right, follow Route 66 to East Randolph

66.2 Junction with Route 14, turn left (north) in center of East Randolph

66.6 Pit starts on left, possible camera stop, geology is similar to that at Stop 5 with Lake Hitchcock bottom deposits overlying esker gravels

66.9 Pit ends on left

67.9 Pit on left with collapse structures

68.9 Road follows remnant of southernmost gravel bar

70.6 Turn left into pit 0.1 mile north of large brick house on left

STOP 8 WHEATLEY PIT IN GRAVEL BAR

Pebble gravel with cobbles in flat beds was formed in the upper-flow regime. The topography has been modified by man but inspection of aerial photographs of this area shows elongated landforms that are interpreted to be longitudinal bars formed by the outlet stream from Lake Winooski after Lake Hitchcock drained. This locality is 25.6 meters (84 feet) below the minimum projected water plane of Lake Hitchcock.

70.9 Turn left Route 14, proceed north

71.3 Landform on west side of valley is interpreted to be an ice-contact delta built directly into Lake Hitchcock at an approximate elevation of 230 meters (754) feet ASL.

72.0 The house and barn west of Route 14 at the cemetery are located on a streamlined landform interpreted to be a longitudinal bar formed by the outlet stream from Lake Winooski after Lake Hitchcock drained

72.4 Village of East Brookfield

72.8 Route 65 on left

73.5 Note streamlined appearance of plowed field on right

74.4 Red house on right is on a post-Lake Hitchcock fan formed by the dissection of an ice-contact delta that was graded to Lake Hitchcock

75.2 Enter Williamstown Gulf, a V-shaped valley that probably was occupied by an outlet stream draining the Winooski

River basin during each advance and retreat of several ice sheets

76.5 House on left marks approximate spot where Lake Hitchcock projection intersects the topography

77.0 CAUTION, TURN LEFT ACROSS TRAFFIC, ENTER DIRT ROAD. The road follows the margin of the outlet channel from Lake Winooski

78.0 Park on right near junction with Route 14

STOP 9 THRESHOLD OF GLACIAL LAKE WINOOSKI

The area behind the white house east of Route 14 represents the drainage divide between the Winooski River and the Connecticut River drainage basins. This locality represents the lowest spot on the margin of the Winooski drainage basin east of the Green Mountains. As long as the ice sheet blocked the Winooski River from draining to the west this threshold was occupied by an outlet stream draining to the south by way of the valley of the Third Branch of the White River. The elevation is about 279 meters (915 feet) ASL.

Turn left (north) on Route 14 to proceed to Williamstown (2.5 miles). From Williamstown: Barre is 6 miles north on Route 14 and Exit 5 of I-89 is 4 miles west on Route 65

Turn right on Route 14 for points south